Dynamic mechanical load testing

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- Mission:
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  - Educate the next generation of technologists
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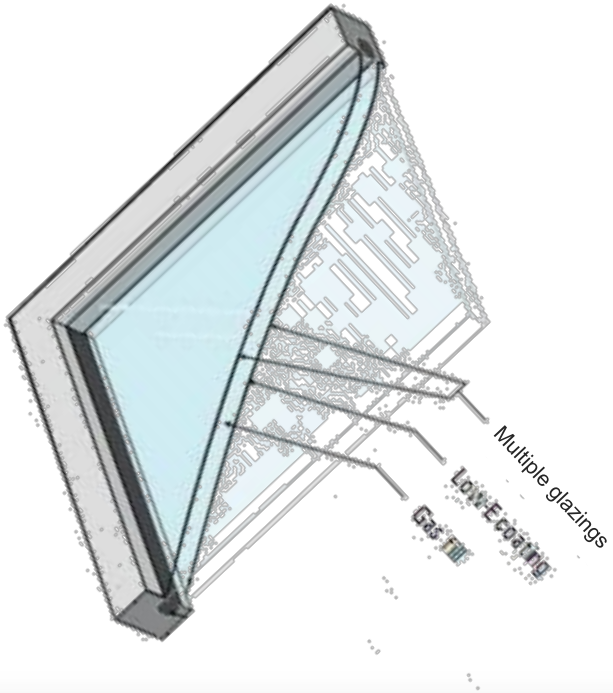
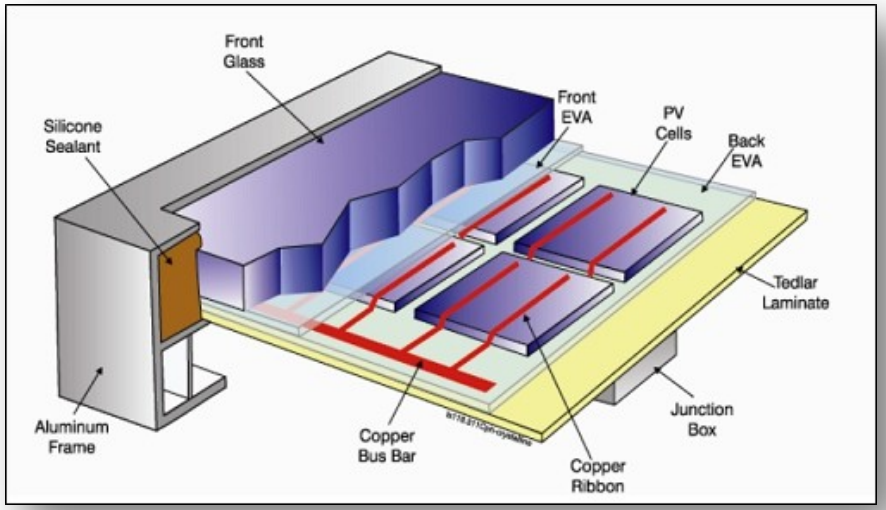
Dynamic wind loading: from windows to PV modules





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Wind load testing of windows

http://www.rationel.co.uk/professionals/information/durability-tests/wind-resistance/

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Wind load testing of PV modules

K.-A. Weiss, M. Assmus, S. Jack, M. Koehl, "Measurement and simulation of dynamic mechanical loads on PV-modules," *Proc. SPIE 7412, Reliability of Photovoltaic Cells, Modules, Components, and Systems II, 741203*, 2009.

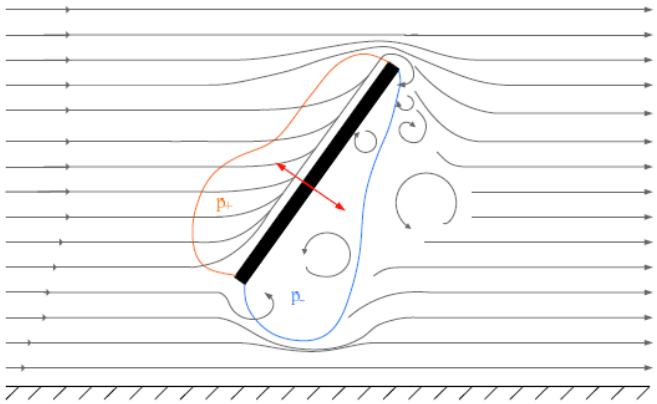
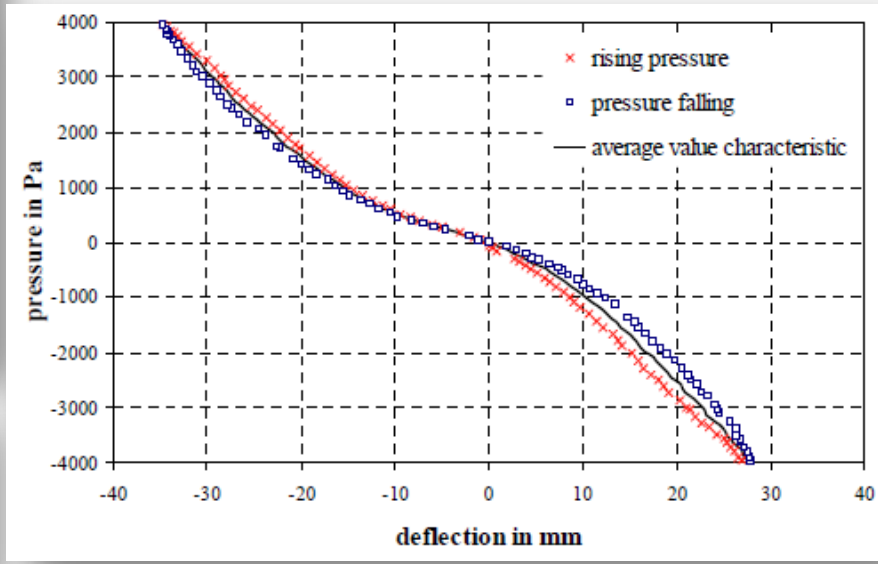
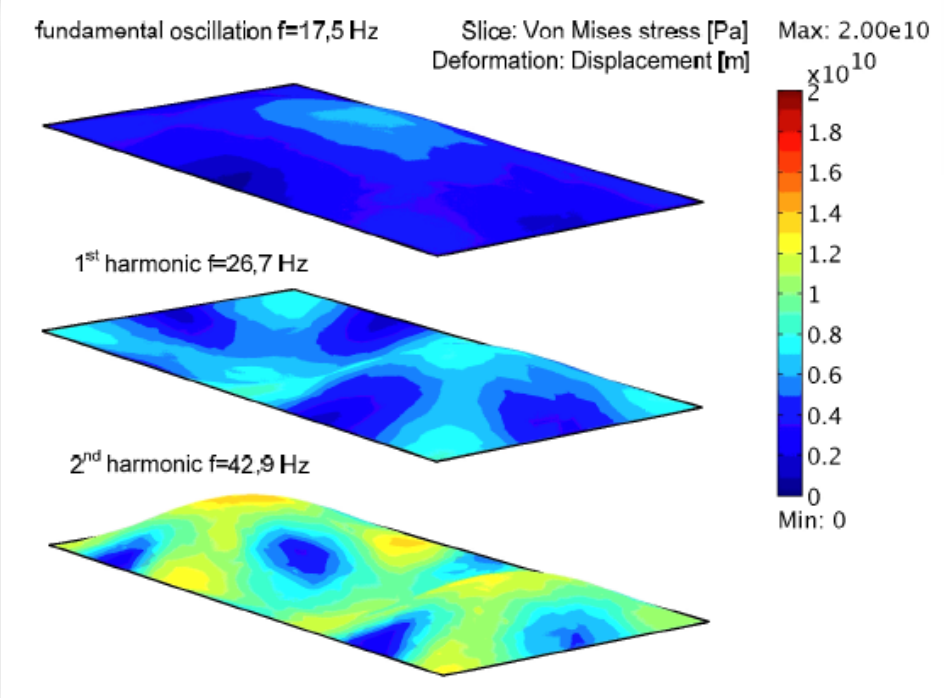


Fig. 1. Scheme of a free standing module in the air flow (black) with positive (orange) and negative pressure range (blue) as well as resulting movement (red) due to flow separation.[1]





Leads to:

- Cracked glass
- Cracked cells
- Cracked interconnect ribbons
- Solder joint failures

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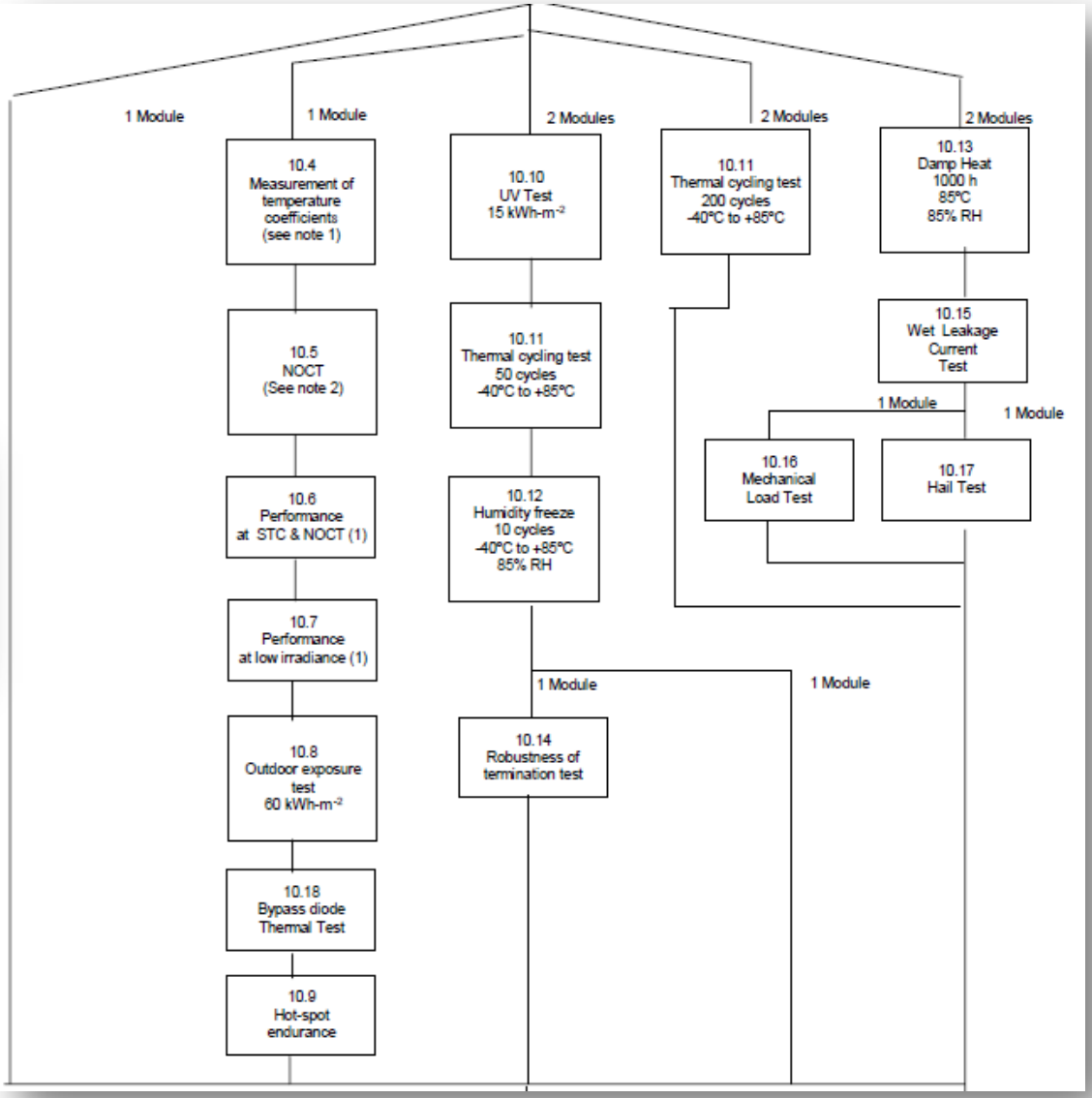
Module Qualification

NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
61215

Deuxième édition
Second edition
2005-04



→No mechanical load testing(!)

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Proposed "Qualification Plus"

2.4 Current Efforts to Improve Qualification Test Standards

Test standards are typically revised every few years to reflect new knowledge. In response to the observations of failures in the field the standards committees have developed or are developing a number of new standards. Some of these are summarized in Table 4.

Table 4. Summary of Standards under Development or not yet adopted into Qualification Tests

Standard or proposal	Description	Status
All locations		
IEC 62782 Dynamic Mechanical Load Testing for PV Modules EN12211 Windows and doors. Resistance to wind load. Test method.	Apply ±1000 Pa at a rate of 1 to 3 cycles/min for 1000 cycles with current flow; quantify power loss	Refining draft
IEC 62804 Potential-Induced Degradation Test for Crystalline Silicon Modules	Apply system voltage in configuration such that leakage current may flow; quantify power loss	Refining draft
ASTM E2481-06 Hot Spot Protection Testing of Photovoltaic Modules	Longer stress: *e.g.* 50 h at 1 kW/m² [34]	Issued
IEC 62852 Connectors for DC-application in photovoltaic systems – Safety requirements and tests	Set of tests for electrical, thermal,	IEC is refining draft;

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JPL Block Tests - 1981

Block V Solar Cell Module Design and Test Specification for Intermediate Load Applications – 1981

LSA Engineering Area

February 20, 1981

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

C. MECHANICAL LOADING TEST PROCEDURE

Panel-type modules shall be subjected to a cyclic load test in which the module is supported only at the design support points and a uniform load normal to the module surface is cycled 10,000 times in alternating negative and positive directions. Cycle rate shall not exceed 20 cycles/min. The module circuitry shall be instrumented to verify that no open circuits or ground faults occur during the test. Cyclic Pressure-Load Developmental Testing of Solar Panels, JPL Document 5101-19, February 1977, describes techniques suitable for the performance of this test.

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IEC 62782 Dynamic mechanical load testing for photovoltaic (PV) modules

Draft Procedure:

1.	Place the test module in the dynamic loading system. Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.
2.	Apply the dynamic mechanical load and cycle it 1000 times using a maximum pressure of ± 1000 Pa and a rate of 1 to 3 cycles per minute. The application of the maximum positive and negative pressure shall be at least 7 ± 3 seconds in duration.
3.	Monitor continuity throughout the test.
4.	Redo all of the initial measurements. Note any changes to the module observed using the IR and EL cameras including the number of cells, interconnect, and/or electrical bonds broken by the dynamic mechanical cycling.

- Does not specify follow-on environmental exposure (e.g., temperature cycling and humidity freeze)

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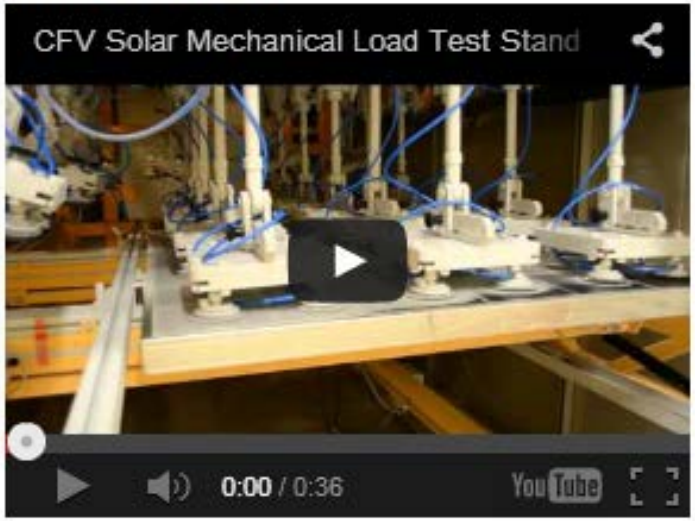
Cyclic loading at low temperature: CFV Test Laboratory

CFV solar test laboratory

JOINTLY OWNED BY: CSA Group | Fraunhofer ISE | Fraunhofer USA | VDE INSTITUTE

CFV Solar Mechanical Load Test Stand
January 18, 2013



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Foundations of IEC 62782

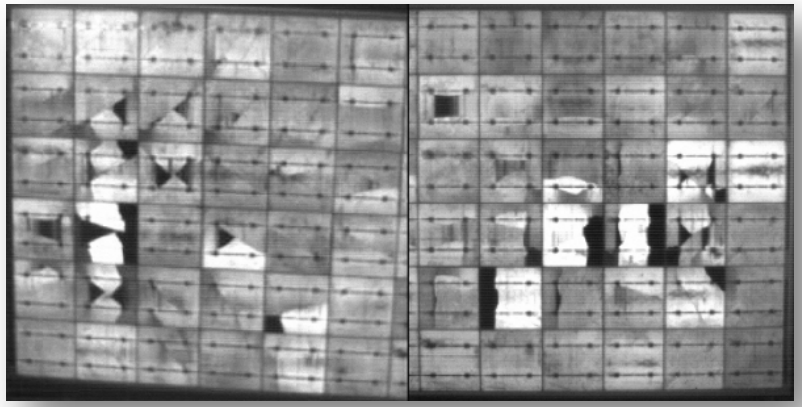

Fig. 3. NIR image of Module F after losing 21.6% through the 1000DMLC/50TC/10HF sequence of tests.

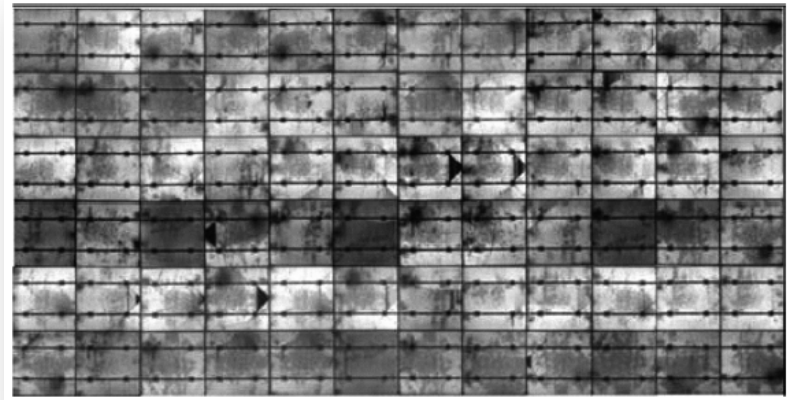

Figure 6. NIR of Module C after 1000 DMLC/50TC/10HF

Table 1. Power loss from accelerated testing of modules with thin cells

Module	Test	Power Loss
A	500 Thermal Cycles	-1.4%
B	500 Thermal Cycles	-0.8%
C	1250 Hrs Damp Heat	+0.8%
D	1250 Hrs Damp Heat	+1.3%
E	1000 DMLC	-1.6%
E	1000 DMLC/50 TC	-1.9%
E	1000 DMLC/50TC/10HF	-3.0%
F	1000 DMLC	-1.4%
F	1000 DMLC/50TC	-5.2%
F	1000 DMLC/50TC/10HF	-21.6%

Table 2. Power loss from accelerated testing sequence after improving the processes and cell handling procedures

Module	A	B	C	D
Power Loss in % After 1000DMLC	+0.2	+0.3	+0.9	+0.3
Power Loss in % After 1000DMLC/50TC	-0.4	-0.1	+0.4	-0.1
Power Loss in % After 1000DMLC/50TC/10HF	-0.7	+0.1	+0.2	-0.4

J.H. Wohlgemuth "The effect of cell thickness on module reliability," *Proc. 33rd IEEE Photovoltaic Specialist Conference*, 2008.

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Comparative Study: Dow Corning silicone encapsulants

NREL NATIONAL RENEWABLE ENERGY LABORATORY	Qualification	Qualification "Plus"	Comparative	Service Life
Purpose	Minimum design qualification	Enhanced design qualification	Comparison of products	Substantiation of warranty
Quantification	Pass/fail	Pass/fail	Relative	Absolute
Climate or application (mounting)	Not differentiated	Not differentiated	Differentiated	Differentiated
Specificity	Silicon, thin-film, CPV	For today, discuss Si only	Package specific?	Product specific
Chamber test times	Modules: ~ 6 weeks	Modules: ~ 3 months Materials: ~ 6 months	TBD	3 years ?

S. Kurtz, J. Wohlgemuth, M. Kempe, N.Bosco, P. Hacke, D. Jordan, D. Miller, "Defining a Technical Basis for Confidence in PV Investments," *IEEE Reliability Symposium*, 2013

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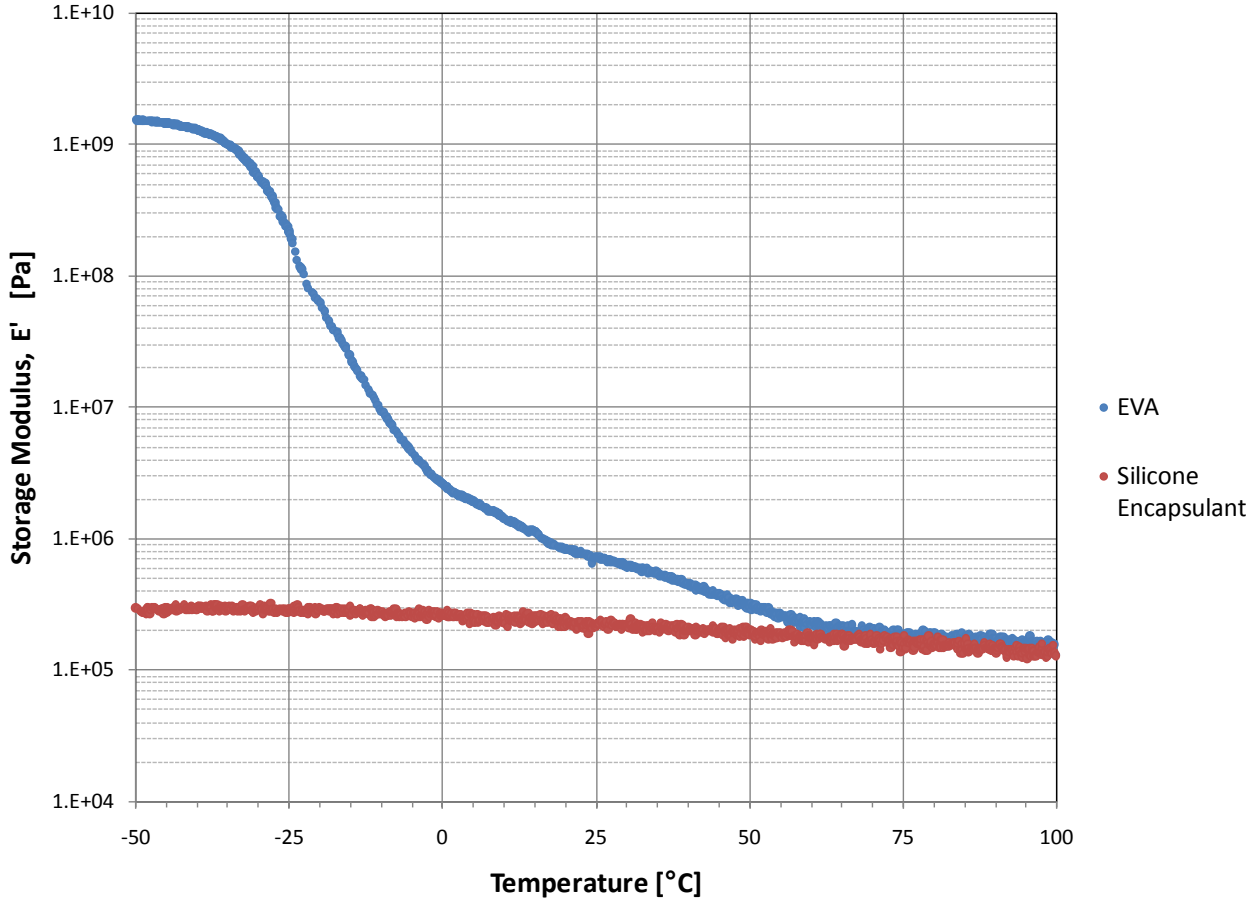
Comparative Study – EVA and Silicone Encapsulation



- **EVA exhibits a glass transition at around -20 °C**
- **Silicone encapsulant has no thermal transitions in the range of -50 °C to 100 °C**

R. Mickiewicz, B. Li, D.M.J. Doble, T. Christian, J. Lloyd, A. Stokes, C. Voelker, M. Winter, B. Ketola, A. Norris, N. Shephard, "Effect of Encapsulation Modulus on the Response of PV Modules to Mechanical Stress," Proc. 26th EU-PVSEC, 2011.

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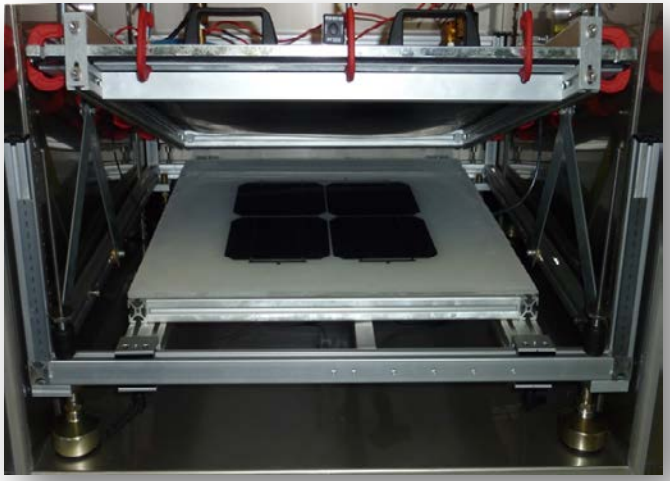
Dynamic Mechanical Load Test Setup



- Custom built mechanical test stand for load testing in environmental chamber
  - Uniform load profile using inflatable bladder
  - Loading up to ~ 10,000 Pa
  - Capable of dynamic (cyclic) loading at up to ~ 1 Hz
  - Test module dimensions up to 550 mm x 550 mm

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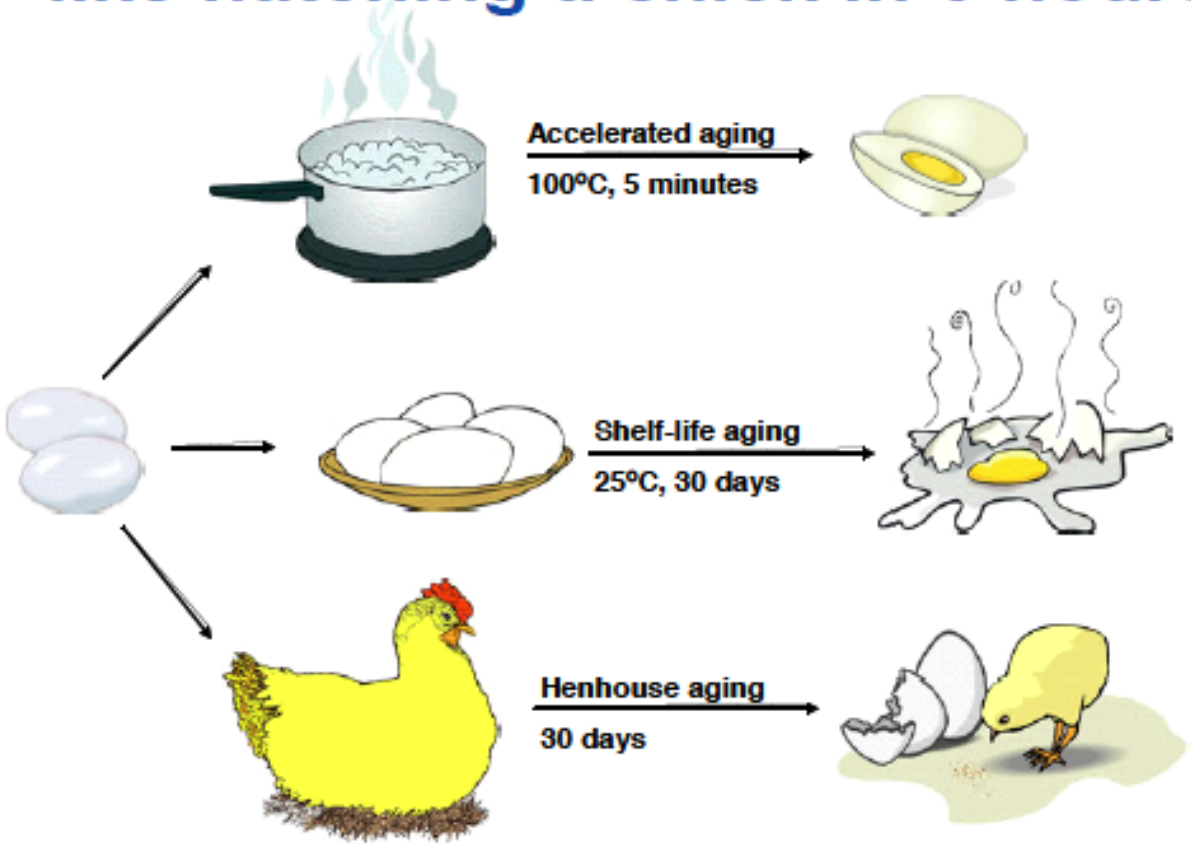
Accelerating 25 y into 3 months is like hatching a chick in 6 hours!



Some processes cannot be accelerated quantitatively > 10X

NREL National Renewable Energy Laboratory

S. Kurtz, J. Wohlgemuth, M. Kempe, N.Bosco, P. Hacke, D. Jordan, D. Miller, "Defining a Technical Basis for Confidence in PV Investments," *IEEE Reliability Symposium*, 2013

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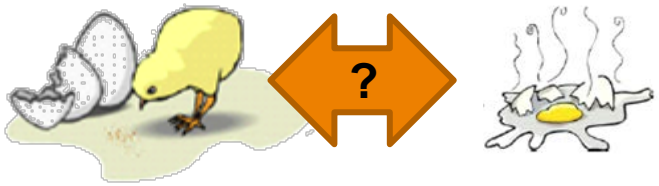
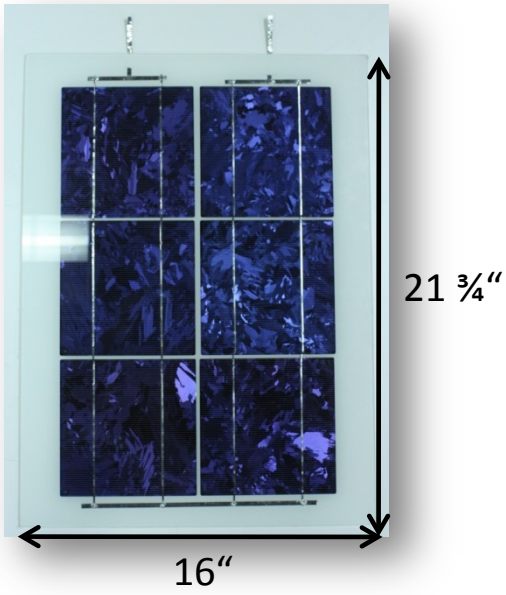
EVA and Silicone Encapsulation: Procedure

Encapsulants	Temperatures	Loads	Notes
Silicone EVA	-30 °C ambient 85 °C	Static: 1 hr @ 2400 Pa 1 hr @ 5400 Pa 1 hr @ 7000 Pa Dynamic (0.5 Hz): 10 000 cycles @ 5400 Pa	Static loading was performed in sequence on a single module, with characterization after each load cycle. Total of 24 modules were tested (3 temperatures, 2 encapsulant materials, 2 cell thicknesses, static & dynamic load).



- 6“ multi-crystalline solar cells
  - 160-µm and 200-µm thickness
  - 2 x 3-cell modules
- I-V characteristics on solar simulator
- Electroluminescence



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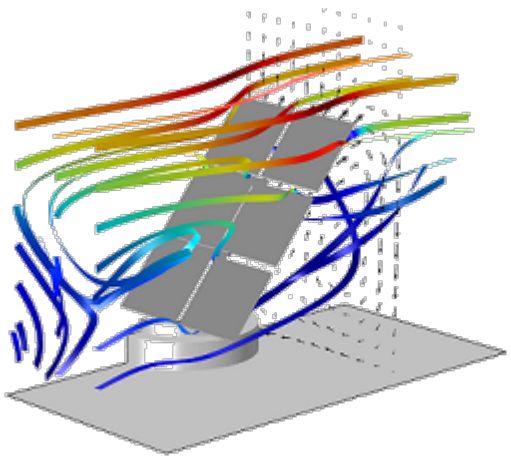
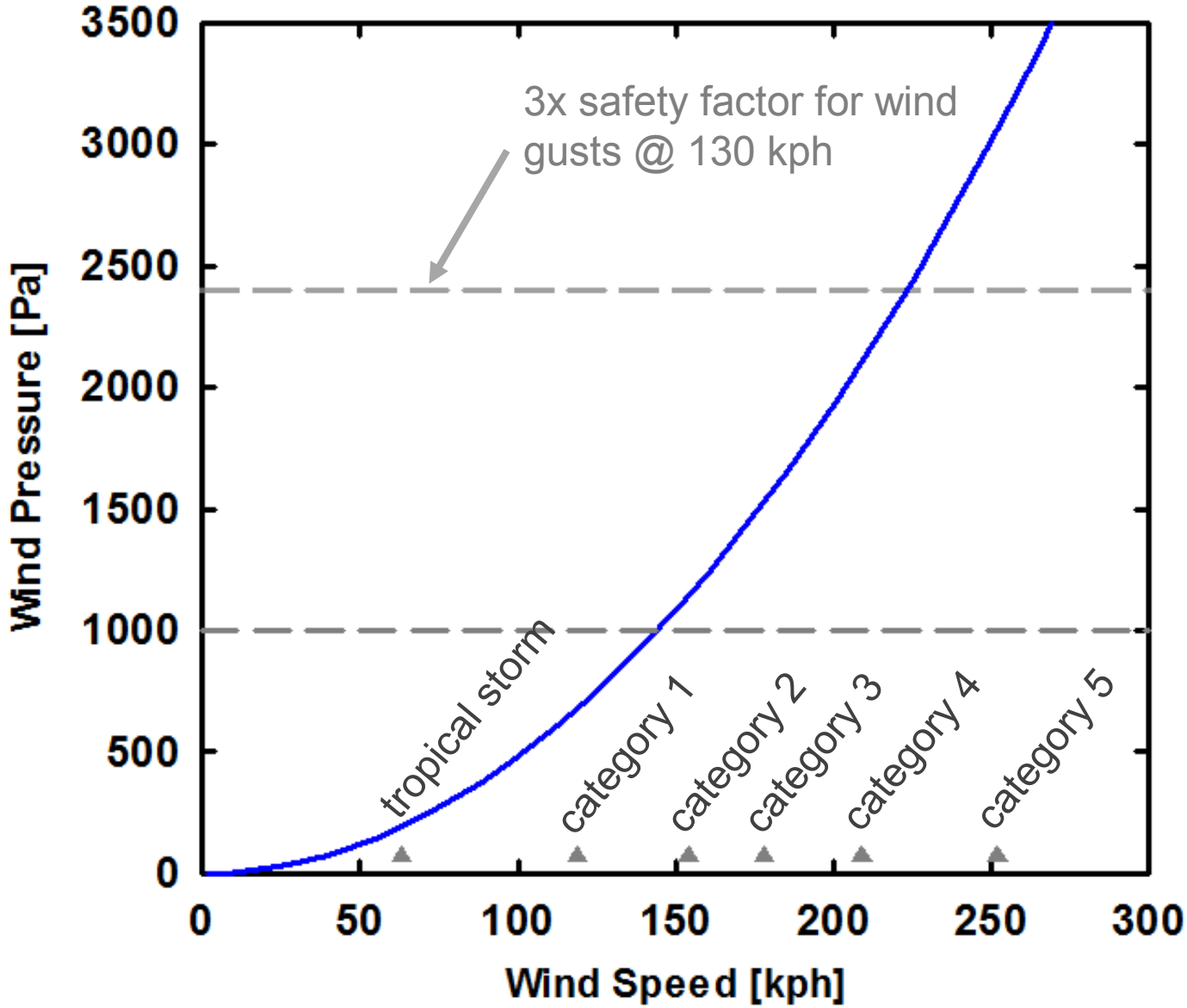
Wind pressure vs. wind speed





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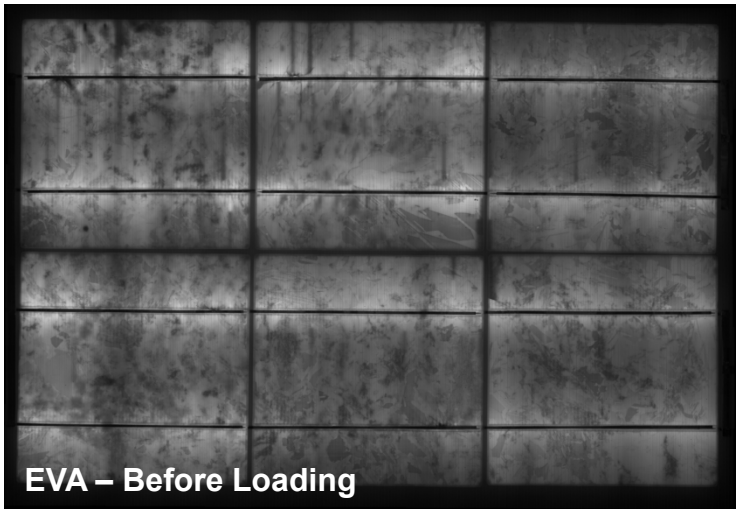
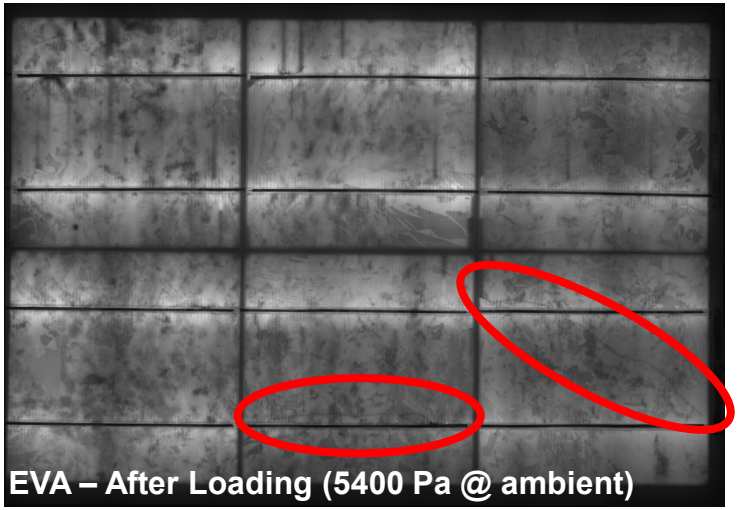
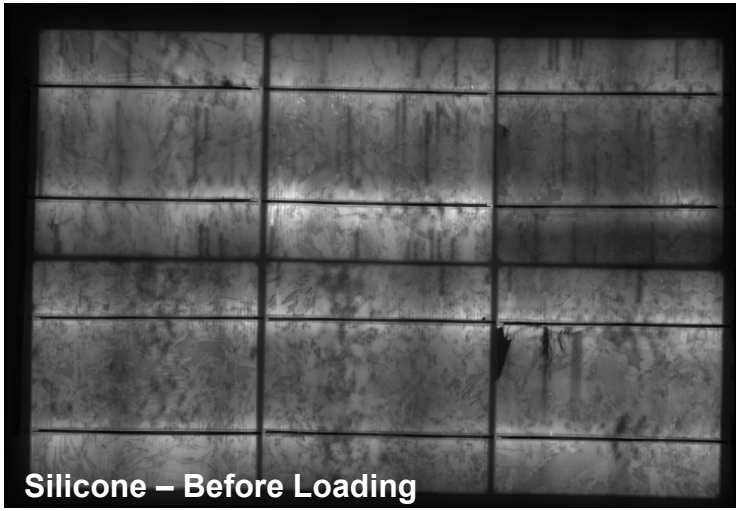
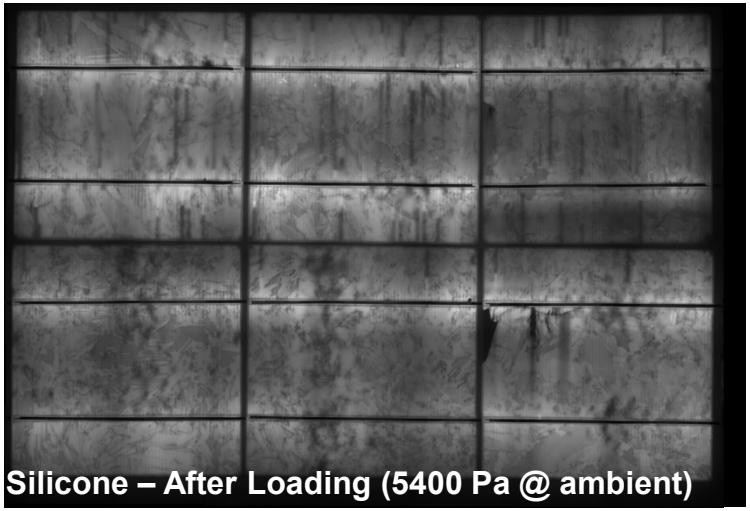
Results – Electroluminescence Imaging









- Cells in EVA-based modules were more cracked than in silicone-based modules

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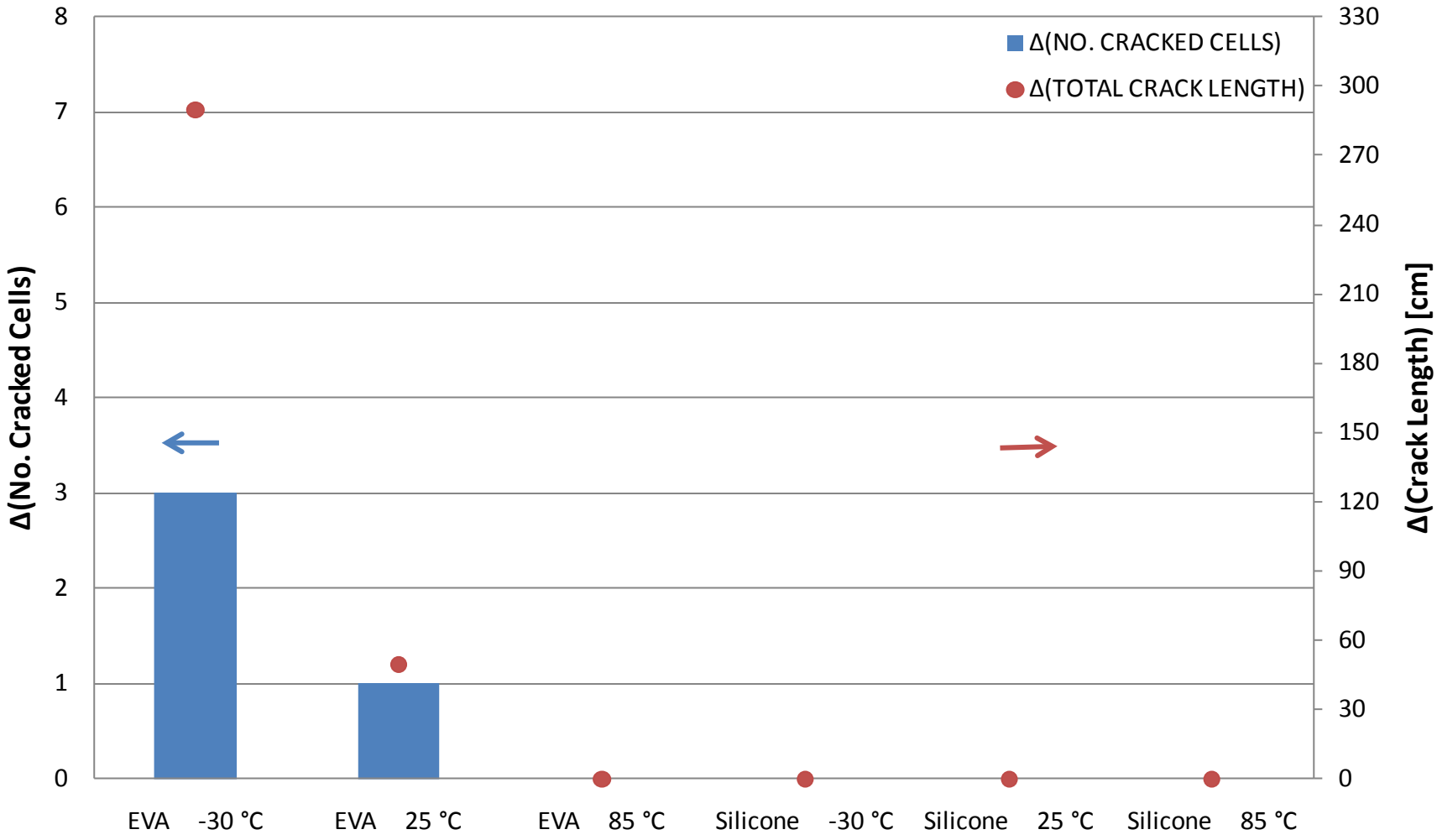
Results – Crack Analysis (160-µm cells)



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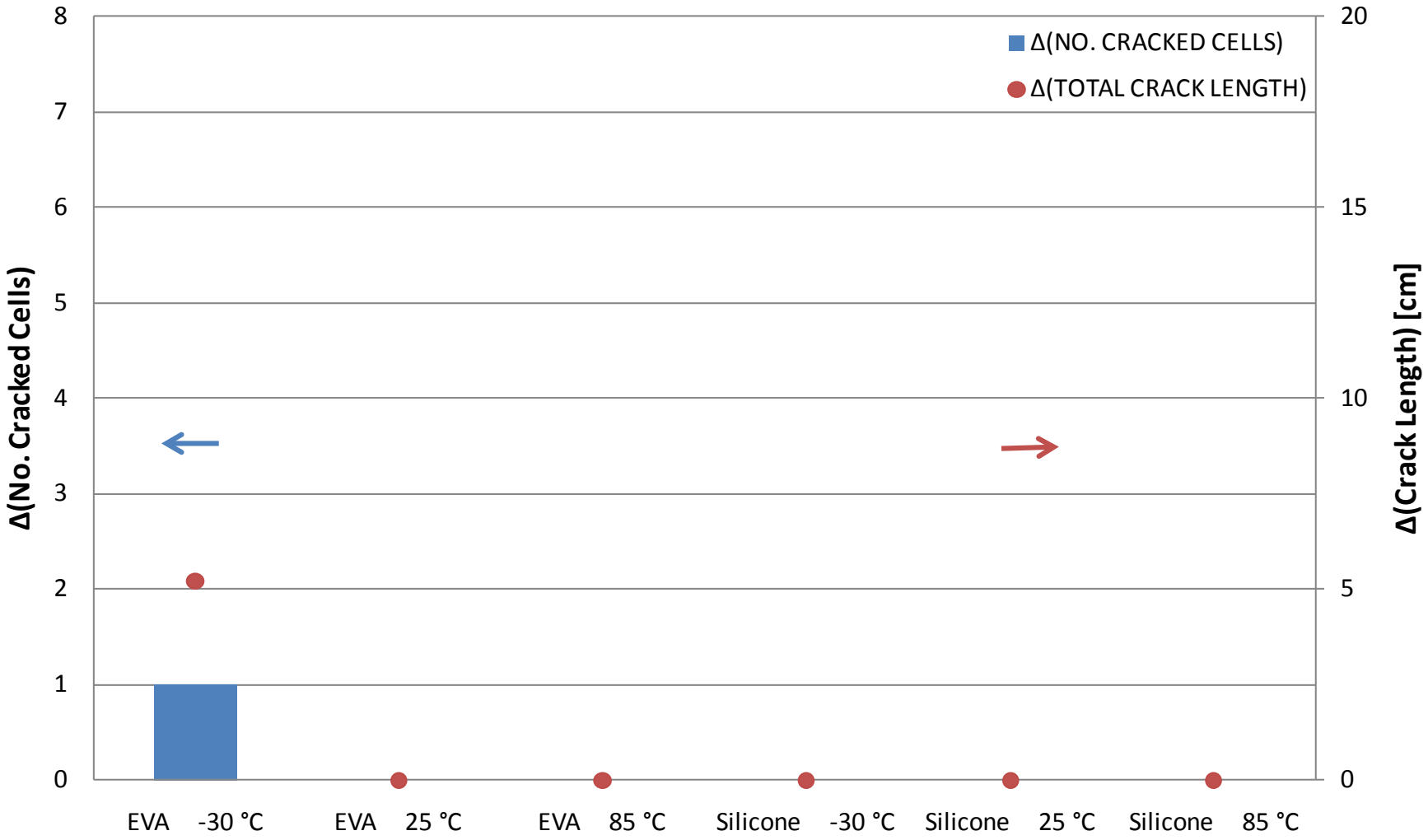
Results – Crack Analysis (200-µm cells)



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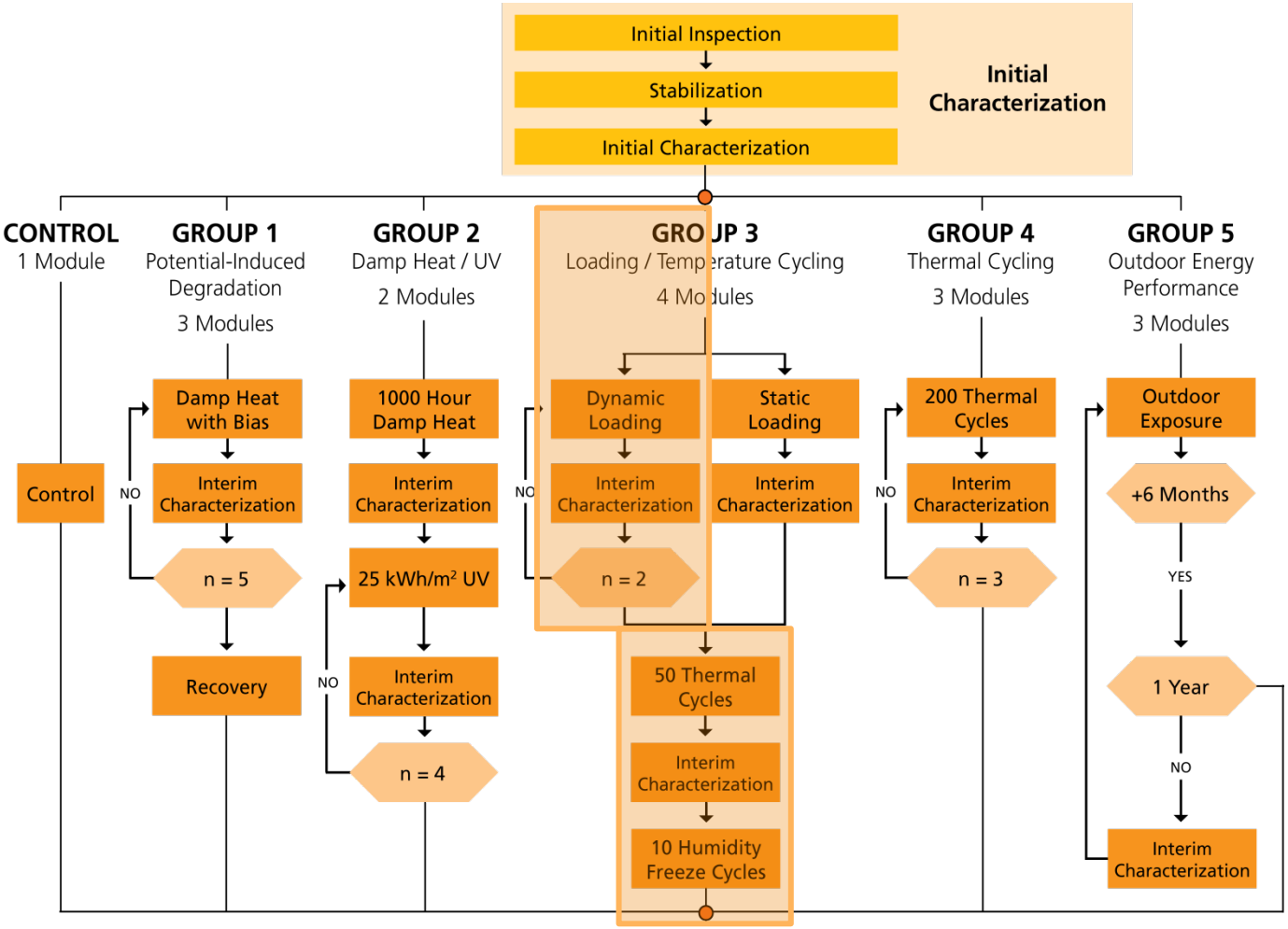
Fraunhofer PV Durability Initiative



D. Meakin, C. Schmid, G. S. Kinsey, "Fraunhofer PV Durability Initiative for solar modules", *PV International*, ed. 20, pp. 77-87, 2013.

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Fraunhofer PV Durability Initiative: context

NREL NATIONAL RENEWABLE ENERGY LABORATORY	Qualification	Qualification "Plus"	Comparative	Service Life
Purpose	Minimum design qualification	Enhanced design qualification	Comparison of products	Substantiation of warranty
Quantification	Pass/fail	Pass/fail	Relative	Absolute
Climate or application (mounting)	Not differentiated	Not differentiated	Differentiated	Differentiated
Specificity	Silicon, thin-film, CPV	For today, discuss Si only	Package specific?	Product specific
Chamber test times	Modules: ~ 6 weeks	Modules: ~ 3 months Materials: ~ 6 months	TBD	3 years ?

S. Kurtz, J. Wohlgemuth, M. Kempe, N.Bosco, P. Hacke, D. Jordan, D. Miller, "Defining a Technical Basis for Confidence in PV Investments," *IEEE Reliability Symposium*, 2013

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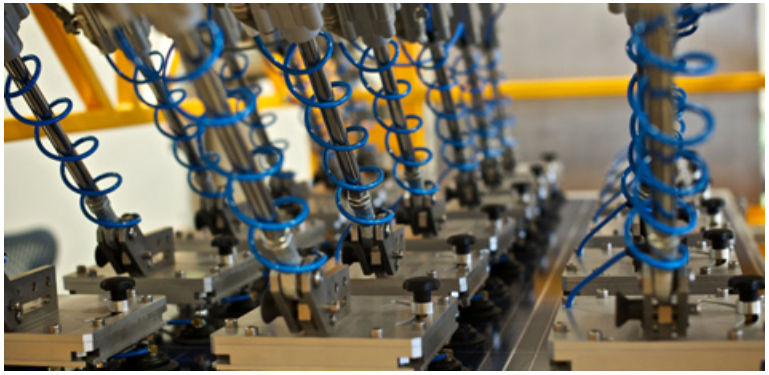
Group 3: Dynamic (cyclic) load



1. **Dynamic Load:**
   - -30°C
   - 2400 Pa
   - 1 Hz
   - Two iterations of 500 cycles
2. **Thermal cycling (50 cycles)**
3. **Humidity freeze (10 cycles)**

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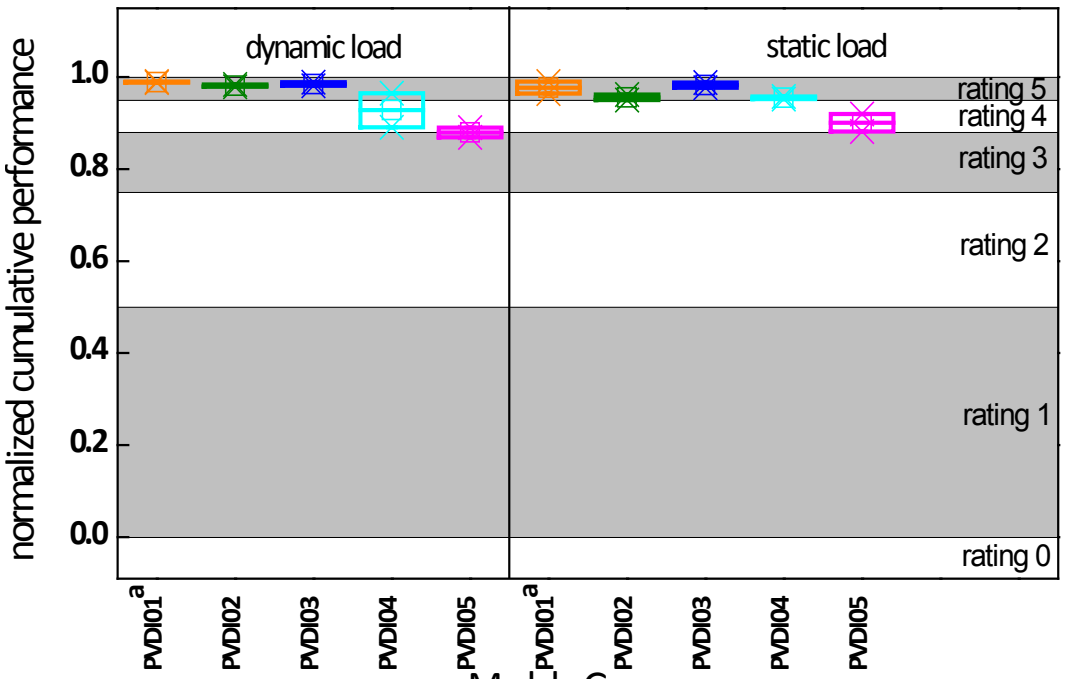
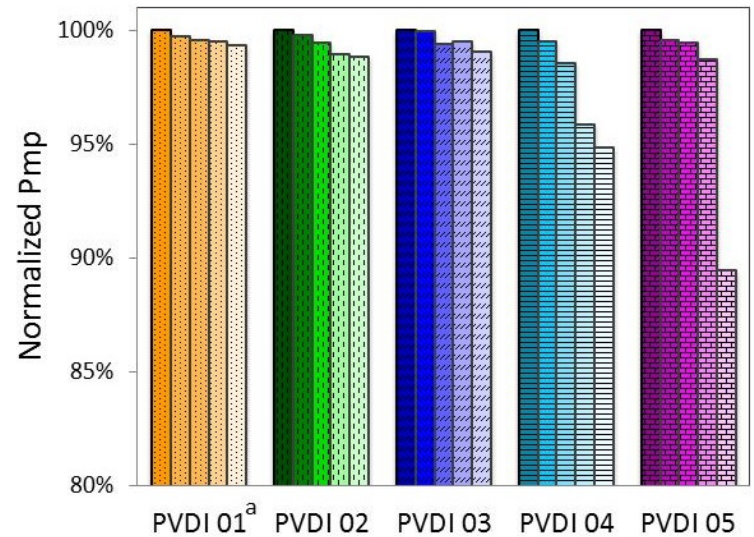
Results: dynamic load





Module ID	Environmental conditions				
	Potential Stress	Humidity/ Radiation	Dynamic Load	Static Load	Thermal Cycling
PVDI 01[a]	5	5	5	5	5
PVDI 02	4	5	5	5	5
PVDI 03	4	5	5	5	2
PVDI 04	5	5	4	5	2
PVDI 05	5	5	3	4	4

- Five of the “top-ten” c-Si modules from 2010 were tested

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